

INKJET PRINTING APPARATUS AND ACTUATOR CONTROLLER AND  
ACTUATOR CONTROLLING METHOD USED IN INKJET PRINTING  
APPARATUS

5

BACKGROUND OF THE INVENTION

[0001]

1. Field of the Invention

The present invention relates to an inkjet printing  
apparatus for ejecting ink onto a record medium to print,  
10 and also to an actuator controller and an actuator  
controlling method used in the inkjet printing apparatus.

[0002]

2. Description of Related Art

A printing head in an inkjet printer includes therein  
15 an ink tank and pressure chambers. Each pressure chamber  
is supplied with ink from the ink tank. When an actuator  
is driven to change the volume of a pressure chamber, ink  
in the pressure chamber is pressurized to be ejected  
through a nozzle connected to the pressure chamber.  
20 Printing in a serial-type inkjet printer is performed with  
reciprocating such an inkjet printing head along the width  
of a print paper.

[0003]

U.S. Patent No. 6,527,354 discloses a technique for  
25 making a head in an inkjet printer eject two of large and

small ink droplets through each nozzle successively in the order of the large and small ink droplets. In this technique, two different pulses, i.e., an ejection pulse and an additional pulse for pulling back part of an ink droplet, which is going to get away from the nozzle, into the ink passage, are applied in this order to the actuator unit. In case of a system for the so-called "fill before fire", as the ejection pulse, a pulse is adopted having its pulse width substantially equal to half the acoustic resonance period of each pressure chamber.

[0004]

In the above system, however, because two different pulses of the ejection and additional pulses are supplied to the actuator to eject two of large and small ink droplets successively in that order, the pulse waveform is relatively complicated. The more complicated the pulse waveform is, the more longer the occupation time of a series of the pulse train required for ejecting a series of ink droplets. That makes difficult to achieve a high-speed printing. Moreover, at a certain printing speed, the following problem may arise. That is, the room is reduced for adding another pulses that improve the print quality by, e.g., canceling a pressure wave remaining within the ink passage after the first ink ejection operation when two ink ejection operations are successively performed.

## SUMMARY OF THE INVENTION

[0005]

An object of the present invention is to provide an  
5 inkjet printing apparatus using a relatively simple pulse  
waveform to be supplied to an actuator for ejecting two of  
large and small ink droplets through each nozzle  
successively in the order of the large and small ink  
droplets, and also to provide an actuator controller and an  
10 actuator controlling method used in the inkjet printing  
apparatus.

[0006]

According to an aspect of the present invention, an  
inkjet printing apparatus comprises a plurality of pressure  
15 chambers each having one end connected to a nozzle; an  
actuator that can take two states of a first state wherein  
the volume of a pressure chamber is  $V_1$ , and a second state  
wherein the volume of the pressure chamber is  $V_2$  larger  
than  $V_1$ ; and an actuator controller for supplying a voltage  
20 pulse to the actuator to change a state of the actuator  
from the first state to the second state and then to the  
first state again so that ink is ejected through the nozzle,  
a pulse width  $T_w$  of the voltage pulse being shorter than a  
pulse width  $T_{max}$  at which a maximum ejection speed of ink  
25 ejected from the nozzle is obtained.

[0007]

According to another aspect of the present invention,  
an actuator controller is provided for controlling the  
drive of an actuator included in an inkjet printing  
5 apparatus, the inkjet printing apparatus comprising a  
plurality of pressure chambers each having one end  
connected to a nozzle. The actuator can take two states of  
a first state wherein the volume of a pressure chamber is  
 $V_1$ , and a second state wherein the volume of the pressure  
10 chamber is  $V_2$  larger than  $V_1$ . The actuator controller  
supplies a voltage pulse to the actuator to change a state  
of the actuator from the first state to the second state  
and then to the first state again so that ink is ejected  
through the nozzle. A pulse width  $T_w$  of the voltage pulse  
15 is shorter than a pulse width  $T_{max}$  at which a maximum  
ejection speed of ink ejected from the nozzle is obtained.

[0008]

According to still another aspect of the present  
invention, a method is provided of controlling the drive of  
20 an actuator included in an inkjet printing apparatus, the  
inkjet printing apparatus comprising pressure chambers each  
having one end connected to a nozzle. The actuator can  
take two states of a first state wherein the volume of a  
pressure chamber is  $V_1$ , and a second state wherein the  
25 volume of the pressure chamber is  $V_2$  larger than  $V_1$ . A

state of the actuator changes from the first state to the second state and then to the first state again so that ink is ejected through the nozzle. The voltage pulse is supplied to the actuator, the voltage pulse having a pulse width  $T_w$  shorter than a pulse width  $T_{max}$  at which a maximum ejection speed of ink ejected from the nozzle is obtained.

[0009]

According to the invention, without applying two pulses having a complicated waveform to the actuator, two of large and small ink droplets can be successively ejected through a nozzle in the order of the large and small ink droplets. Therefore, with relatively simplifying the waveform of a pulse for driving the actuator, the room can be increased for improving the print quality by, e.g., canceling the pressure wave remaining within the ink passage.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Other and further objects, features and advantages of the invention will appear more fully from the following description taken in connection with the accompanying drawings in which:

FIG. 1 illustrates a general construction of an inkjet printer (inkjet printing apparatus) according to an embodiment of the present invention;

FIG. 2 is a bottom view of parallel inkjet heads in  
FIG. 1;

FIG. 3 is a partial sectional view of an inkjet head  
in FIG. 1;

5        FIG. 4 is an enlarged sectional view illustrating an  
ink passage in an ink passage unit in a head main body of  
an inkjet head in FIG. 1;

FIG. 5 is a sectional view taken along line V-V in  
FIG. 4, illustrating a specific structure of an actuator  
10 unit;

FIG. 6 is a block diagram of a general electrical  
construction of the inkjet printer of FIG. 1;

FIG. 7A is a graph roughly showing the waveform of a  
voltage pulse supplied from a driver IC to the actuator  
15 unit;

FIG. 7B is a graph, corresponding to FIG. 7A, showing  
a change in voltage of an individual electrode in the  
actuator unit having received the voltage pulse of FIG. 7A;

FIGS. 8A to 8C illustrate states of ejecting ink  
20 through a nozzle by the drive of an actuator unit, in the  
order of time elapsing;

FIGS. 9 are tables showing results of measurements of  
ejection speeds and size ratios of ink droplets when the  
pulse width  $T_w$  of the voltage pulse of FIG. 7A is variously  
25 changed;

FIGS. 10 are graphs showing the results of FIGS. 9;

FIG. 11 is a sectional view of an modification of the actuator unit, corresponding to FIG. 5; and

FIG. 12 is a sectional view of an modification of the ink passage unit, corresponding to FIG. 4.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0010]

FIG. 1 illustrates a general construction of an inkjet printer (inkjet printing apparatus) according to an embodiment of the present invention. The inkjet printer 1 of this embodiment is a color inkjet printer having four inkjet heads 2. Within the inkjet printer 1, a paper feed unit 11 and a paper discharge unit 12 are provided in left and right portions of FIG. 1, respectively. In the inkjet printer 1, formed is a paper conveyance path for conveying a paper from the paper feed unit 11 to the paper discharge unit 12.

[0011]

A pair of paper feed rollers 5a and 5b are disposed immediately downstream of the paper feed unit 11 for putting forward a paper as a print medium from the left to the right in FIG. 1. In the middle of the paper conveyance path, two belt rollers 6 and 7 and a looped conveyor belt 8 are provided. The conveyor belt 8 is wrapped around the

belt rollers 6 and 7 to be stretched between them.

[0012]

The conveyor belt 8 has a two-layered structure made up of a polyester base body impregnated with urethane and a  
5 silicone rubber. The silicone rubber is disposed in the outer portion of the conveyor belt 8 to form a conveyor face. A paper fed through the pair of paper feed rollers 5a and 5b is kept on the conveyor face of the conveyor belt 8 by chucking force. In this state, the paper is conveyed  
10 downstream, i.e., rightward in FIG. 1, by driving one belt roller 6 to rotate clockwise in FIG. 1 as indicated by an arrow 50.

[0013]

Pressing members 9a and 9b are provided at positions  
15 for feeding a paper onto the conveyor belt 8 and discharging the paper from the conveyor belt 8, respectively. Either of the pressing members 9a and 9b is for pressing the paper onto the conveyor face of the conveyor belt 8 so as to prevent the paper from separating  
20 from the conveyor face.

[0014]

A peeling device 10 is provided in the paper conveyance path immediately downstream of the conveyor belt 8, i.e., on the right in FIG. 1. The peeling device 10  
25 peels off the paper, which is kept on the conveyor face of



the conveyor belt 8 by chucking force, from the conveyor face so that the paper can be conveyed toward the rightward paper discharge unit 12.

[0015]

5        Each of the four inkjet heads 2 has, at its lower end, a head main body 2a. Each head main body 2a has a rectangular section. The head main bodies 2a are arranged close to each other with the length of each head main body 2a being perpendicular to the paper conveyance direction, 10 i.e., perpendicular to FIG. 1. That is, this printer 1 is a line type printer. The bottom of each of the four head main bodies 2a faces the paper conveyance path. In the bottom of each head main body 2a, a large number of nozzles 13 (see FIG. 4) are provided each having a small-diameter 15 ink ejection port 13a (see FIG. 2). The four head main bodies 2a eject ink of magenta, yellow, cyan, and black, respectively.

[0016]

20        The head main bodies 2a are disposed such that a narrow clearance is formed between the lower face of each head main body 2a and the conveyor face of the conveyor belt 8. The paper conveyance path is formed within the clearance. In this construction, while a paper, which is being conveyed by the conveyor belt 8, passes immediately 25 below the four head main bodies 2a in order, the respective

color inks are ejected through the corresponding nozzles 13 (see FIG. 4) toward the upper face, i.e., the print face, of the paper to form a desired color image on the paper.

[0017]

5           FIG. 3 illustrates a partial sectional view of an inkjet head 2. The inkjet head 2 is attached through a holder 15 to an adequate member 14 provided within the printer 1. The holder 15 has an inversed-T shape in a side view, made up of a vertical portion 15a and a horizontal  
10           portion 15b. The vertical portion 15a is fixed to the member 14 with a screw 16. A base block 17 and a head main body 2a are fixed in this order to the lower face of the horizontal portion 15b with a spacer member 40 being interposed therebetween.

15           [0018]

          An ink reservoir 17a is formed within the base block 17 along the length of the base block 17, i.e., perpendicularly to FIG. 3. The ink reservoir 17a is always filled up with ink supplied from a non-illustrated ink tank  
20           through an adequate pipe.

[0019]

          The head main body 2a includes an ink passage unit 20 and an actuator unit 19. As will be described later, ink passages each including a pressure chamber are formed in  
25           the ink passage unit 20. The actuator unit 19 applies

pressure to ink in the pressure chamber. The ink passage unit 20 has an inlet port 20a (see FIG. 2 or 3) facing the base block 17. The ink passage unit 20 is bonded to the base block 17 so that the inlet port 20a is connected to the ink reservoir 17a in the base block 17. Thus, ink in the ink reservoir 17a can flow into the ink passage unit 20 through the inlet port 20a.

[0020]

The actuator unit 19 is bonded to the upper face of the ink passage unit 20, more specifically, in a region other than the region where the upper face of the ink passage unit 20 is bonded to the base block 17. The actuator unit 19 is separated from the base block 17. That is, although the base block 17 is bonded to the ink passage unit 20 in the vicinity of the inlet port 20a, the base block 17 is separated from the head main body 2a in the other region. The actuator unit 19 is disposed within the separation region. As illustrated with broken lines in FIG. 2, each actuator unit 19 has a trapezoidal shape in plane. Actuator units 19 are arranged in two rows in a zigzag manner along the length of each head 2. Each actuator unit 19 is disposed so that its parallel opposite sides, i.e., the upper and lower sides, are along the length of the ink passage unit 20. Oblique sides of neighboring actuator units 19 overlap each other along the width of the ink

passage unit 20. The region of the lower face of the ink passage unit 20 corresponding to the region where each actuator unit 19 is bonded, is an ink ejection region.

[0021]

5 Pairs of inlet ports 20a of each ink passage unit 20 as described above are arranged in two rows in a zigzag manner so as to correspond to regions where no actuator unit 19 is disposed. Because the plural inlet ports 20a are thus arranged at intervals along the length of each ink  
10 passage unit 20, even in case of a long head 2, ink in each ink reservoir 17a can be stably supplied to the ink passage unit 20 with suppressing the flow resistance.

[0022]

Next, an ink passage in the ink passage unit 20 will  
15 be described in more detail with reference to FIG. 4. FIG. 4 is an enlarged sectional view illustrating an ink passage in the ink passage unit 20 in a head main body 2a in FIG. 1.

[0023]

Referring to FIG. 4, the ink passage unit 20 has a  
20 structure wherein nine thin metallic plates 21, 22, 23, 24, 25, 26, 27, 28, and 29 are put in layers. A manifold channel 30 is formed over the fifth to seventh plates 25 to 27 from the upper side. The manifold channel 30 is connected to an inlet port 20a as described above, through  
25 a non-illustrated passage. A connection hole 31 is formed

in the fourth plate 24 immediately above the fifth plate 25.  
The connection hole 31 is connected to an aperture 32  
formed in the third plate 23.

[0024]

5       The aperture 32 is connected through a connection  
hole 33 formed in the second plate 22, to one end of a  
pressure chamber 34 formed in the first plate 21. The  
pressure chamber 34 is for applying pressure to ink by  
means of deformation of the actuator unit 19 fixed to the  
10 upper face of the ink passage unit 20. One pressure  
chamber 34 is provided to correspond to each nozzle 13.  
The other end of the pressure chamber 34 is connected  
through a nozzle connection hole 35 formed through the  
second to eighth plates, to a tapered nozzle 13 formed in  
15 the ninth plate 29, i.e., nozzle plate. An ink ejection  
port 13a is formed at the tip end of the nozzle 13.

[0025]

Thus, within the ink passage unit 20, formed are ink  
passages each individually corresponding to each nozzle 13  
20 and extending from the manifold channel 30 to the aperture  
32, the pressure chamber 34, the nozzle connection hole 35,  
and the nozzle 13.

[0026]

Each pressure chamber 34 has a planer shape of  
25 elongated rhomboid or parallelogram with their corners

rounded, though the illustration is omitted.

[0027]

Next, the actuator unit 19 will be described in more detail with reference to FIG. 5. FIG. 5 is a sectional  
5 view taken along line V-V in FIG. 4.

[0028]

Referring to FIG. 5, the actuator unit 19 includes five piezoelectric sheets 51, 52, 53, 54, and 55 having the same thickness of about 15 micrometer. The piezoelectric  
10 sheets 51 to 55 are made into a continuous layered plate (continuous plate layer) disposed over many pressure chambers 34 formed within one ink ejection region in the inkjet head 2. Because the piezoelectric sheets 51 to 55 are disposed as a continuous plate layer over many pressure  
15 chambers 34, the mechanical rigidity of the piezoelectric element can be kept high and the responsibility of ink ejection of the inkjet head 2 can be improved.

[0029]

An about 2 micrometer-thick common electrode 61a is  
20 interposed between the first and second piezoelectric sheets 51 and 52 from the upper side. Also, an about 2 micrometer-thick common electrode 61b is interposed between the third and fourth piezoelectric sheets 53 and 54. Either of the common electrodes 61a and 61b is one  
25 conductive sheet extending substantially over the whole

area of one actuator unit 19. The common electrodes 61a and 61b are grounded in a non-illustrated region so that the area of either of the common electrodes 61a and 61b corresponding to all pressure chambers 34 is kept at the  
5 ground potential.

[0030]

An about 1 micrometer-thick individual electrode 62a is provided on the upper face of the first piezoelectric sheet 51 to correspond to each pressure chamber 34. An  
10 about 2 micrometer-thick individual electrode 62b made like the individual electrode 62a is interposed between the second and third piezoelectric sheets 52 and 53. The region where the individual electrodes 62a and 62b are disposed works as a pressure generation portion A for  
15 applying pressure to ink in the pressure chamber 34.

[0031]

No electrode is provided between the fourth and fifth piezoelectric sheets 54 and 55 and on the lower face of the fifth piezoelectric sheet 55.

20 [0032]

Each of the electrodes 61a, 61b, 62a, and 62b is made of an Ag-Pd-base metallic material for example.

[0033]

As illustrated in FIGS. 4 and 5, a flexible printed  
25 circuit (FPC) 41 as a power supply member is bonded to the

upper face of the actuator unit 19. As illustrated in FIG. 3, the FPC 41 extends out from sides of the inkjet head main body 2a and the extensions are bent upward to be connected to a driver IC 80 (see FIG. 1) disposed on a side face of the member 14. The driver IC 80 is connected to a circuit board 81. Each pair of individual electrodes 62a and 62b are electrically connected through a lead provided within the FPC 41 independently for each pair of individual electrodes 62a and 62b, to the driver IC 80 and further to an MCU (Micro Controller Unit) 82 mounted on the circuit board 81 (see FIG. 1). Thus, each pressure chamber 34 can be controlled in electric potential independently of another pressure chamber 34.

[0034]

In the inkjet head 1 of this embodiment, the first to third piezoelectric sheets 51 to 53 have been polarized along the thickness of each sheet. Therefore, when a pair of individual electrodes 62a and 62b are set at a potential different from that of the common electrodes 61a and 61b to apply an electric field to the piezoelectric sheets 51 to 53 along the polarization, the portion of each of the piezoelectric sheets 51 to 53 to which the electric field is applied works as an active portion that distorts by a piezoelectric effect. The active portion is going to extend or contract in the thickness of the sheet and to



contract or extend in the plane of the sheet perpendicular to the thickness of the sheet by the transverse piezoelectric effect. On the other hand, because the remaining two piezoelectric sheets 54 and 55 are inactive  
5 layers having no regions sandwiched by the individual electrodes 62a and 62b and the common electrodes 61a and 61b, they can not be deformed by themselves. That is, the actuator unit 19 has a unimorph type structure in which the upper three piezoelectric sheets 51 to 53 distant from each  
10 pressure chamber 34 are layers including active portions and the lower two piezoelectric sheets 54 and 55 near each pressure chamber 34 are inactive layers.

[0035]

In this structure, when the driver IC 80 is  
15 controlled to set a pair of individual electrodes 62a and 62b at a predetermined positive or negative potential relative to that of the common electrodes 61a and 61b so that an electric field is applied in the same direction as the polarization, the portions, i.e., active portions, of  
20 the piezoelectric sheets 51 to 53 sandwiched by the electrodes contract in the plane of each sheet. On the other hand, because the piezoelectric sheets 54 and 55 as inactive layers are not influenced by the electric field, they do not contract by themselves and are adapted to  
25 restrict deformations of the active portions. As a result,

a difference in strain along the polarization is generated between the upper piezoelectric sheets 51 to 53 and the lower piezoelectric sheets 54 and 55, and thereby the piezoelectric sheets 51 to 55 are deformed into a convex  
5 shape toward the corresponding pressure chamber 34, which is called unimorph deformation.

[0036]

Control of the actuator unit 19 will be now described with reference to FIG. 6. The MCU 82 shown in FIG. 6 is a  
10 controller disposed on the circuit board 81 of FIG. 2, for general control of the inkjet printer 1. The MCU 82 includes therein an MPU (Micro Processor Unit), a ROM, and a RAM, any of which is not illustrated. The ROM stores therein kinds of pulse waveform data corresponding to  
15 different total volumes of ink droplets to be ejected in accordance with image gradation. The RAM can store therein image data to be printed, as occasion demands. The MPU generates serial print data based on the image data stored in the RAM, and outputs the serial print data together with  
20 the kinds of pulse waveform data stored in the ROM, to the driver IC 80.

[0037]

The driver IC 80 includes therein a shift register, a multiplexer, and a drive buffer, any of which is not  
25 illustrated. The shift register converts the serial print

data received from the MCU 82, into parallel data to output individual data for each nozzle 13 of the head 2. The multiplexer selects adequate one out of the kinds of pulse waveform data for ink ejection, on the basis of the data  
5 received from the shift register, and outputs the selected data to the drive buffer. The drive buffer generates a voltage pulse having a predetermined level, on the basis of the data received from the multiplexer, and supplies the voltage pulse through the FPC 41 (see FIG. 3) to the  
10 individual electrodes 62a and 62b of the actuator unit 19 corresponding to each nozzle 13. Thereby, the actuator unit 19 corresponding to each nozzle 13 is driven to form a desired image on a print paper.

[0038]

15 Next, the waveform of the voltage pulse generated by the driver IC 80 to be applied to individual electrodes 62a and 62b of the actuator unit 19 and a change in voltage of the individual electrodes 62a and 62b having received the voltage pulse will be described with reference to FIGS. 7A  
20 and 7B. FIG. 7A is a graph roughly showing the waveform of the voltage pulse supplied from the driver IC 80 to the actuator unit 19. FIG. 7B is a graph, corresponding to FIG. 7A, showing a change in voltage of the individual electrodes 62a and 62b in the actuator unit 19 having  
25 received the voltage pulse of FIG. 7A.

[0039]

In the waveform of the voltage pulse of FIG. 7A, the voltage is  $V_0$  in the ranges (a) and (c) and the voltage is zero in the range (b). The time  $T_w$  of the range (b) is

5 "the pulse width of the voltage pulse" according to the invention. The individual electrodes 62a and 62b of the actuator unit 19 having received such a voltage pulse form a capacitor. The individual electrodes 62a, 62b and the common electrode 61a, 61b sandwich the piezoelectric sheets

10 51, 52 and 53 as a dielectric as shown in FIG. 5. The individual electrodes 62a, 62b exhibit a change in voltage as shown in FIG. 7B with a delay corresponding to a charge time of the capacitor. The time points  $T_1$  and  $T_2$  and the time  $T_w$  of FIG. 7A correspond to the time points  $T_1$  and  $T_2$

15 and the time  $T_w$  of FIG. 7B, respectively.

[0040]

Further, drive of the actuator unit 19 having received the voltage pulse of FIG. 7A will be described with reference to FIGS. 8A to 8C. FIGS. 8A to 8C

20 illustrate states of ejecting ink through a nozzle 13 by the drive of the actuator unit 19, in the order of time elapsing.

[0041]

FIG. 8A corresponds to (a) of FIG. 7B wherein a

25 predetermined voltage  $V_0$  is applied to individual

electrodes 62a and 62b. In this state, the lower face of the actuator unit 19 in the region of the pressure generation portion A of FIG. 5 is deformed into a convex shape toward the corresponding pressure chamber 34. In  
5 this state, the volume of the pressure chamber 34 is V1. This state will be referred to as first state of the actuator unit 19.

[0042]

FIG. 8B corresponds to (b) of FIG. 7B wherein the  
10 voltage of the individual electrodes 62a and 62b is zero. In this state, the convex deformation of the actuator unit 19 as illustrated in FIG. 8A has disappeared. The volume V2 of the pressure chamber 34 at this time increases as compared with the volume V1 of the pressure chamber 34 as  
15 shown in FIG. 8A. This state will be referred to as second state of the actuator unit 19. As a result of such an increase in volume of the pressure chamber 34, ink is sucked from the corresponding manifold channel 30 into the pressure chamber 34.

20 [0043]

FIG. 8C corresponds to (c) of FIG. 7B wherein the individual electrodes 62a and 62b are again set at the voltage V0. In this state, the lower face of the actuator unit 19 is deformed into a convex shape toward the pressure  
25 chamber 34 like FIG. 8A. That is, at this time, the

actuator unit 19 is in the first state. As a result,  
pressure is applied to ink in the pressure chamber 34 and  
thereby two separate large and small ink droplets d1 and d2  
are ejected through the ink ejection port 13a at the tip of  
5 the corresponding nozzle 13. The ink droplets d1 and d2  
will reach the print face of a print paper to form dots.

[0044]

As described above, in the drive of the actuator unit  
19 of this embodiment, the volume of the pressure chamber  
10 34 is once increased (FIG. 8A to 8B) to generate a negative  
pressure wave, and then the volume of the pressure chamber  
34 is again decreased (FIG. 8B to 8C) at the timing when  
this pressure wave returns as a positive pressure wave  
traveling toward the nozzle 13 side after being reflected  
15 by the end parts of the ink passage within the ink passage  
unit 20. This is a technique so-called "fill before fire".  
By this technique, the positive pressure wave having  
reflected as described above can be superimposed on the  
positive pressure wave generated by the deformation of the  
20 actuator unit 19, to apply intense pressure to ink.  
Accordingly, the size of the pressure chamber 34 can be  
decreased or the drive voltage for the actuator unit 19 can  
be lowered. This technique is advantageous in the points  
of a highly dense arrangement of pressure chambers 34, a  
25 decrease in size of the inkjet head 2, and the running cost

upon driving the inkjet head 2.

[0045]

In case of adopting "fill before fire" having the above-described advantages in particular, two separate ink droplets can be ejected by one ink ejection action because of the relation between vibration of ink meniscus formed in the ink ejection port 13a and the timing when the pressure chamber reaches the ink meniscus portion.

[0046]

10 In this embodiment, as shown in FIG. 7A, the width  $T_w$  of the voltage pulse to be applied to the actuator unit 19 is controlled to be shorter than the pulse width  $T_{max}$  at which the maximum ejection speed of ink ejected from the nozzle 13 is obtained. This pulse width  $T_{max}$ , in this  
15 embodiment, corresponds to a time period in which the pressure wave propagates from the ink ejection port 13a connected to one end of the pressure chamber 34, to the outlet of the aperture 32 near the pressure chamber 34 side, connected to the other end of the pressure chamber 34 (the  
20 part indicated by an arrow within the passage in FIG. 4). The width  $T_w$  is preferably controlled to be not less than 0.7  $T_{max}$  and not more than 0.8  $T_{max}$ . In other words, as apparent from FIG. 7B, the time period  $T_w$  from the time point  $T_1$  when the actuator unit 19 starts to change from  
25 the first state to the second state, until the time point

T2 when the actuator unit 19 starts to change from the second state to the first state, is controlled to be shorter than T<sub>max</sub>, preferably, not less than 0.7 T<sub>max</sub> and not more than 0.8 T<sub>max</sub>.

5 [0047]

Thereby, with a simple waveform (see FIG. 7A) of the voltage pulse for driving the actuator unit 19 in comparison with a case of applying two pulses, two of large and small ink droplets such as d1 and d2 of FIG. 8C can be  
10 successively ejected in the order of the large and small ink droplets. Therefore, the room can be increased for improving the print quality by, e.g., canceling the pressure wave remaining within the ink passage.

[0048]

15 The above-described knowledge has been obtained from results of an experiment made by the present inventor. The experiment will be described below in detail.

[0049]

In the experiment, three kinds of inkjet head main  
20 bodies 2a were prepared in which each pressure chamber 34 is varied in shape, as T<sub>max</sub> = 5.4 microseconds, T<sub>max</sub> = 5.2 microseconds, and T<sub>max</sub> = 5.0 microseconds. Voltage pulses as shown in FIG. 7A having different pulse widths T<sub>w</sub> were applied to each head main body 2a. Under these conditions,  
25 the ejection speeds of two ink droplets d1 and d2 ejected



through an ink ejection port 13a were measured and each ejected ink droplet was photographed and image-processed to measure the sizes of ink droplets d1 and d2.

[0050]

5        FIGS. 9 are tables showing results of measurements of ejection speeds and size ratios of ink droplets when the pulse width Tw of the voltage pulse of FIG. 7A is variously changed, in the respective cases of Tmax = 5.4 microseconds, Tmax = 5.2 microseconds, and Tmax = 5.0 microseconds. FIGS.  
10    10 are graphs showing the results of FIGS. 9. In the experiment, an ink droplet d1 first ejected through an ink ejection port 13a is supposed to be a first ink droplet, and an ink droplet d2 successively ejected through the ink ejection port 13 is supposed to be a second ink droplet.  
15    The size ratio means the ratio of their sizes (the diameter of the first ink droplet d1)/(the diameter of the second ink droplet d2). Therefore, when the size ratio is larger than one, the first ink droplet d1 is larger than the following second ink droplet d2. In each of FIGS. 10, the  
20    axis of abscissas represents pulse width Tw, the left axis of ordinates does ink droplet ejection speed, and the right axis of ordinates does ink droplet size ratio.

[0051]

25        The ejection speed of the ink droplet becomes higher as the pressure wave synthesized during the above-described

"fill-before-fire" gets larger.

[0052]

As seen from FIGS. 9 and 10, when the pulse width  $T_w$  of the voltage pulse is increased, the ejection speed of the ink droplet gradually becomes higher, and then drops after reaching a peak value.

[0053]

As shown in the uppermost graph of FIGS. 10, when  $T_{max} = 5.4$  microseconds, the ink droplet size ratio exceeded one in the range wherein the pulse width  $T_w$  was not more than 4.3 microseconds, which was nearly equal to 0.8  $T_{max}$ . The ink droplet size ratio of more than one means that the first ink droplet  $d_1$  first ejected is larger in volume than the following second ink droplet  $d_2$ . Because the small second ink droplet  $d_2$  is higher in speed than the large first ink droplet  $d_1$ , this reduces the difference between the timing when the first ink droplet  $d_1$  reaches the print face and the timing when the second droplet  $d_2$  reaches the print face. Also, as shown in the middle graph of FIGS. 10, when  $T_{max} = 5.2$  microseconds, the ink droplet size ratio exceeded one in the range wherein the pulse width  $T_w$  was not more than 4.0 microseconds, which was nearly equal to 0.8  $T_{max}$ . As shown in the lowermost graph of FIGS. 10, when  $T_{max} = 5.0$  microseconds, the ink droplet size ratio exceeded one in the range

wherein the pulse width  $T_w$  was not more than 4.0  
microseconds, which was nearly equal to  $0.8 T_{max}$ .

[0054]

In the range wherein  $T_w$  is not more than  $0.8 T_{max}$ ,  
5 any of the three graphs of FIGS. 10 shows a tendency that  
the ink droplet ejection speed reduces, i.e., the pressure  
applied to ink reduces, as the pulse width  $T_w$  decreases.  
In consideration of a request that the size of each  
pressure chamber 34 is decreased for a highly dense  
10 arrangement in order to realize a high-resolution inkjet  
head, and a request that the consumption power of the  
actuator unit 19 is held down, the higher ink droplet  
ejection speed is superior under the same conditions.  
Considering these in total,  $T_w$  in the range of not more  
15 than  $0.7 T_{max}$  and not less than  $0.8 T_{max}$  is most preferable  
on the points of improvement of print quality, a highly  
dense arrangement of pressure chambers 34, a decrease in  
size of the inkjet head 2, and reduction of the consumption  
power of the actuator unit 19.

20 [0055]

When pressure chambers 34 are densely arranged,  
controlling each pressure chamber 34, that is, controlling  
the actuator unit 19 corresponding to each pressure chamber  
34 may be complicated. However, by adopting the method of  
25 this embodiment, the actuator unit 19 can efficiently be

controlled with realizing a highly dense arrangement of the pressure chambers 34.

[0056]

On the other hand, when the pulse width  $T_w$  is not  
5 less than  $T_{max}$ , because the pulse period is longer than  
that in case of  $T_w$  of less than  $T_{max}$ , a printing operation  
must take a long time and this is inefficient. In addition,  
as clearly shown in the lowermost graph of FIGS. 10, the  
fall of the ink droplet ejection speed is relatively rapid.  
10 For these reasons, it is preferable that the pulse width  $T_w$   
is shorter than  $T_{max}$ .

[0057]

In this embodiment, the actuator unit 19 is driven  
with such a voltage pulse as shown in FIG. 7A applied from  
15 the driver IC 80. Upon ink ejection, the actuator unit 19  
can be controlled accurately and surely in the manner that  
the actuator unit 19 is set to the first, second, and first  
states as in FIGS. 8A to 8C in this order, and, as shown in  
FIG. 7B, the time period  $T_w$  from the timing  $T_1$  when the  
20 actuator unit 19 starts to change from the first state to  
the second state until the timing  $T_2$  when the actuator unit  
19 starts to change from the second state to the first state  
is made equivalent to the pulse width  $T_w$  of the voltage  
pulse.

25 [0058]

In addition to such a line-printing type inkjet printer as in the above embodiment in which printing is performed with moving a print paper relatively to the fixed head main body 2a, the present invention is applicable to, e.g., a serial-printing type inkjet printer in which printing is performed with moving a print paper and reciprocating a head main body 18 perpendicularly to the movement of the print paper.

[0059]

Further, the present invention is not limited to inkjet printers but applicable also to, e.g., inkjet type facsimiles and copying machines.

[0060]

Further, the structure of the head including the actuator unit 19, pressure chambers 34, etc., is not limited to that of the above embodiment. For example, the actuator unit can have a structure as illustrated in FIG. 11. This actuator unit 119 includes two piezoelectric sheets 151 and 152. A common electrode 161 is interposed between the piezoelectric sheets 151 and 152. Individual electrodes 162 are provided on the face of the upper piezoelectric sheet 151 near the FPC 41 so as to correspond to the respective pressure chambers 34. Even in case of an actuator unit thus different in structure from the above-described embodiment, effective control can be made by

applying the present invention. Further, each pressure chamber 34 is not limited to a rhombic or parallelogrammic shape. For example, each pressure chamber 34 may have a rectangular shape. In short, each pressure chamber 34 may have a longitudinal axis along an adequate direction and have its one end connected to a nozzle 13.

[0061]

In the above embodiment, "a time period in which the pressure wave propagates from the ink ejection port 13a to the outlet of the aperture 32 near the pressure chamber 34 side in the ink passage within the ink passage unit 20" corresponds to the pulse width  $T_{max}$  at which the maximum ejection speed of ink is obtained. However, this is not limitative. As shown in FIG. 12, for example, when the head main body 102 does not comprise the aperture 32 (see FIG. 4) and a cylindrical connection hole 133 is formed extending from the pressure chamber 34 to the manifold channel 30, "a time period in which the pressure wave propagates from the ink ejection port 13a to the outlet of the manifold channel 30 near the pressure chamber 34 side in the ink passage within the ink passage unit 20" may be considered to correspond to ' $T_{max}$ ' in the present invention. That is, a value of the pulse width ' $T_{max}$ ' at which the maximum ink ejection speed is obtained varies in accordance with configurations of the ink passage within the ink

passage unit 20.

[0062]

While this invention has been described in  
conjunction with the specific embodiments outlined above,  
5 it is evident that many alternatives, modifications and  
variations will be apparent to those skilled in the art.  
Accordingly, the preferred embodiments of the invention as  
set forth above are intended to be illustrative, not  
limiting. Various changes may be made without departing  
10 from the spirit and scope of the invention as defined in  
the following claims.